Herb layer in silver fir – beech forests in the western Pyrenees: Does management affect species diversity?

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ABSTRACT

Silver fir-beech forests form ecologically important ecosystems in European mountains, where they have been intensively managed due to timber harvesting. Forest management effects can be evaluated using herb layer diversity as an indicator of environmental changes. Therefore, revealing the patterns of herb layer diversity is necessary for developing strategies for sustainable management. Knowledge on management history of fir-beech forests in the western Pyrenees is still limited. In this study we aim to disentangle the environmental drivers of species richness and species composition of these forests emphasizing the role of forest management. We sampled the herb layer vascular plants in 68 plots distributed among 14 silver fir-beech stands of the association *Scillo lilio-hyacinthi-Fagetum sylvaticae* and related diversity patterns with management histories, light conditions and topographic and climatic variables. Four management categories were established: *recently managed*, *long managed*, *recently abandoned* and *long abandoned*. Species richness was analysed by GLMM and species composition by partial CCA and PCNM. Multivariate dispersion analysis was used to assess differences in beta diversity among management categories. Management, continentality and slope had in general a weak effect on species richness, continentality with a positive effect whilst slope and management, in category of *recently abandoned* stands, with a negative effect. In addition, the percentage of large gaps had a moderate effect on *open area* species richness. Species composition was related to slope, ombrothermic index, forest management and spatial effects in terms of neutral processes. *Long managed* forests showed differences in beta diversity with *recently abandoned* and *long abandoned* forests. Our study suggests that environmental variables in combination with spatial effects are the main drivers of species diversity at small sampling scale, highlighting that management plays an important role in these western Pyrenean silver fir-beech forests.

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1. Introduction

Silver fir-beech forests form ecologically important ecosystems in European mountains (Peterken, 1996) from the East Carpathians to the Pyrenees and from the Beskids in Poland to the mountains of northern Greece (Konnert and Bergmann, 1995). Being of high importance for timber harvesting, these forest ecosystems are transformed more than any other forest biome (Hannah et al., 1995). This fact has given rise to studies about the effects of management on species diversity in these forests, in particular on the diversity of the herb layer, which is widely recognised as an important component of the forest ecosystem and its functioning (Gilliam, 2007) and contributes the most to forest plant diversity in temperate forests (Roberts, 2004). As such, it can be used as a measure of environmental changes and human disturbances (Schmidt and Weckesser, 2002). Therefore, understanding the mechanisms that drive herb layer plant distribution is essential for the development of management strategies in temperate forests (Sabatini et al., 2014). In this context, numerous studies in the last decades have been dedicated to herb layer investigation, with the objective to emphasise its role in forest functioning (Brumme and Khanna, 2009).

Forests are complex ecological systems (Kuuluvainen, 2009) and many factors drive herb layer diversity: combination of abiotic constraints, biotic interactions and disturbances in space and time.

Overall mechanisms that drive plant distribution can be summarised in the frame of two theories, niche-based processes (Tilman, 1982) and neutral processes (Nabout et al., 2009). With regards to niche-based processes, previous studies broadly define the main factors that affect herb layer diversity in forests, such as light transmittance and soil water supply (Augusto et al., 2003; Barbier et al., 2008; Härdtle et al., 2003) or forest management (Ramovs and Roberts, 2003). Neutral processes (Hubbell, 2001) include variation in species related to random dispersal and ecological drift (Legendre and Legendre, 2012). Regarding this issue, recent studies have considered both niche and neutral processes as determinants of species diversity (Chase, 2005; Legendre et al., 2009), stressing that relative contribution of these may vary with the spatial scale of analysis (Chase and Knight, 2013).

Among niche-based processes, several studies have highlighted the important role of forest management in Central European beech forests by comparing plant species diversity in managed and unmanaged forests (Brunet et al., 2010). The meta-analysis provided by Paillet et al. (2010) showed that the species richness of vascular plants tends to be higher in managed forests, although the response was heterogeneous, probably due to the contrasting results obtained at the local scale (Burrascano et al., 2009; Schmidt, 2005; Sebastià et al., 2005). These inconsistencies when comparing managed and unmanaged stands across different regions might be the consequence of the lack of detailed information about silvicultural practices (Roberts and Gilliam, 1995). In other words, forest management histories differ among European countries because beech forests have been harvested for centuries by different methods and with different intensities (Peters, 2013).

The present study addresses the issue of forest management effects on the herb layer species diversity for silver fir-beech forests from the western Pyrenees, where silver fir reaches its south-western distribution limit. Although silver fir-beech forests in the western Pyrenees have been studied at large in a floristic sense (Rivas-Martínez et al., 1991; Villar, 1980a), no studies about herb layer diversity and its relation with forest management have been performed to date. The case of the western Pyrenean forests is a complex issue regarding forest management because of unsystematic silvicultural practices conducted in the last two centuries and lack of data. Whilst in south-eastern Europe and in Alpine regions, silver fir-beech forests have been managed by selective logging in the last two centuries (Hahn and Fanta, 2001), in the western Pyrenees, little is known about management history of these forests. Undoubtedly, it was strongly linked to animal husbandry, which significantly influenced forest cover and landscape connectivity. Forest exploitation basically consisted in rather arbitrary logging, depending on local population needs and wood demand. In the last 50 years, animal husbandry and forest management have become less intense because of human migrations and the abandonment of these activities, which led to an increase in forest biomass and landscape changes (Vicente-Serrano et al., 2000). Following the law approval on forest management regulation for this area in the 1970s, forest management became systematic and organised, although some areas remained out of forest inventory and management plans. At the same time, remote and better preserved forests were declared protected areas, such as natural parks and the strict reserve *Aztaparreta,* which was firstly described as virgin forest (Villar, 1980b), but nowadays it is considered an old-growth forest with well developed old-growth attributes without any evidence of past management practices. Because of the valuable information that old-growth forests can provide about natural disturbance processes (Peterken, 1996), this old-growth forest can be taken as a reference when studying plant diversity and tackling forest management issues.

Although the effect of forest management on herb-layer diversity has been addressed in several studies, more research at the local scale is needed in order to obtain sound conclusions through meta-analyses (Paillet et al., 2010). In this context, the present study could contribute to a better general understanding of this issue, moreover if we consider the relevance of these western Pyrenean forests as south-western distribution limit of European silver fir-beech forests. The unsystematic forest management of Pyrenean forests has supposed an additional challenge in our study, which we have tried to clarify in order to better assess its influence on plant diversity.

According to the current literature about forest management effects in silver fir-beech stands in Europe, we expected that forest management would affect species richness and species composition. In particular, due to overall management abandonment of Pyrenean forests, we expected species richness to decrease, although this general pattern may be sensitive to landscape patterns and management history (Paillet et al., 2010). Given the above, the purpose of the present study is to reveal the role of forest management on herb layer diversity in western Pyrenean silver fir-beech forests. We analysed species diversity regarding both species richness and species composition. This study aims to answer (1) which environmental factors drive species richness in silver fir-beech forests from the western Pyrenees? (2) Which factors explain the variation in species composition in these forests? (3) Does management affect species diversity?

2. Material and methods

2.1. Study area

The study area is located in the Spanish part of the western Pyrenees (Fig. 1), in the regions of Navarre and Aragón. The landscape is characterised by mountains and valleys with dominant bedrock formed by limestones and marly flysch, which correspond to the Secondary and Tertiary cover over the Palaeozoic central axis of the Pyrenees (Loidi et al., 2011). Biogeographically, this area belongs to the Alpine region and according to the Global Bioclimatic Classification System developed by Rivas-Martínez (2007), the bioclimate is temperate oceanic, with a mean annual temperature of 8 °C, mean annual rainfall of 1419 mm and a W-E continentality gradient. Long history of livestock and forest exploitation shaped the landscape of this area. Consequently, there is large landscape heterogeneity with semi-natural grasslands, scrublands, natural forests and *Pinus sylvestris* plantations.

The silver fir-beech forests of the area are included in the association *Scillo lilio- hyacinthi-Fagetum sylvaticae* Br.-Bl. ex O. Bolòs 1957, which encompasses omprophilous hyperhumid forests growing on calcareous bedrock (Rivas-Martínez et al., 1991). These forests do not show any clear management history, because of unsystematically conducted silvicultural practices with different intensities during the last century. In particular, the following silvicultural practices have been documented: group selection logging, shelterwood, selective logging system and exclusive fir exploitation.

2.2. Data collection

Silver fir-beech forests in an altitudinal range between 800 and 1700 m a.s.l. were delimited using potential vegetation maps and aerial photographs provided by the Governments of Navarre and Aragón. North faced stands exceeding 30 ha were selected, out of which 14 stands were randomly chosen (Appendix A). Within each stand, four to five plots of 20 m × 20 m were randomly sampled, in